Personal Exposure to Contaminant Sources in a Uniform Velocity Field

Brohus, Henrik; Nielsen, Peter V.

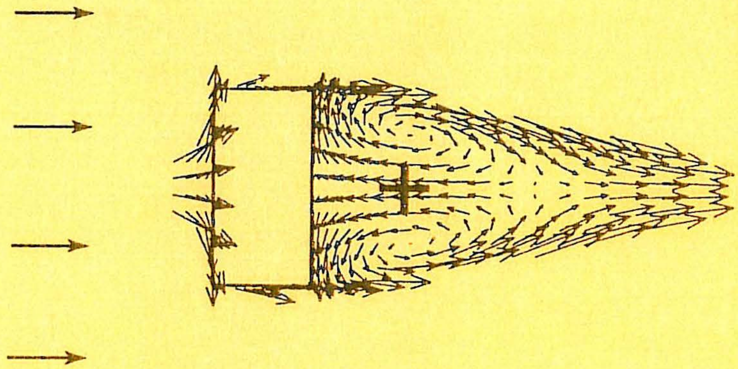
Publication date:
1995

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Brohus, H., & Nielsen, P. V. (1995). *Personal Exposure to Contaminant Sources in a Uniform Velocity Field*. Dept. of Building Technology and Structural Engineering. Indoor Environmental Technology Vol. R9540 No. 53

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITET • AUC • AALBORG • DANMARK



INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 53

Presented at Healthy Buildings '95
Milano, Italy, September 1995

HENRIK BROHUS & PETER V. NIELSEN

PERSONAL EXPOSURE TO CONTAMINANT SOURCES IN A UNIFORM VELOCITY FIELD

DECEMBER 1995 ISSN 1395-7953 R9540

Printed at Aalborg University

INSTITUTTET FOR BYGNINGSTEKNIK
DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITET • AUC • AALBORG • DANMARK

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 53

Presented at Healthy Buildings '95
Milano, Italy, September 1995

HENRIK BROHUS & PETER V. NIELSEN
PERSONAL EXPOSURE TO CONTAMINANT SOURCES IN A UNIFORM VELOCITY FIELD
DECEMBER 1995 ISSN 1395-7953 R9540

PERSONAL EXPOSURE TO CONTAMINANT SOURCES IN A UNIFORM VELOCITY FIELD

Henrik Brohus and Peter V. Nielsen

Aalborg University
Department of Building Technology and Structural Engineering
Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark
Phone: +45 98 15 85 22 Fax: +45 98 14 82 43 E-mail: i6hb@civil.auc.dk

INTRODUCTION

When the task is to control the indoor exposure, it is important to know how persons are exposed to a contaminant source. Personal exposure to a contaminant depends on the ventilation and the location of the source relative to the person. Previous studies have shown that the exposure may differ more than one order of magnitude due to different velocity fields (Brohus and Nielsen, 1994). This fact stresses the importance of taking this parameter into account when we want to control the exposure and develop guidelines for exposure reduction.

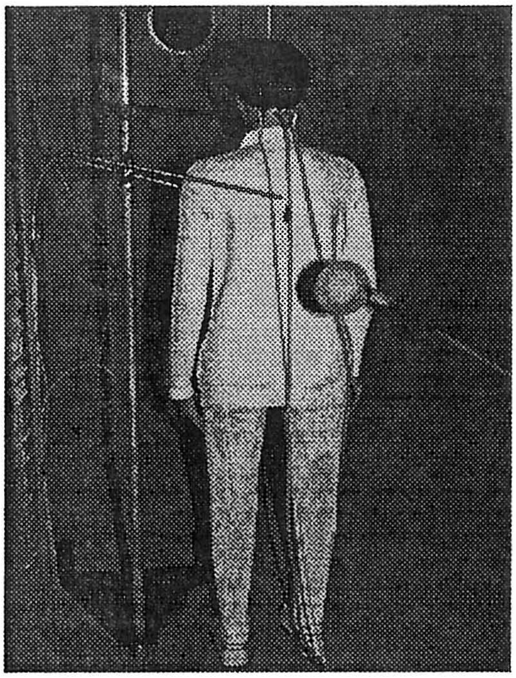
The objective of this study has been to determine the personal exposure to a contaminant source in a uniform velocity field. This was done by full-scale measurements and computer simulations. The results showed a significant dependence on the velocity field both regarding the direction and the magnitude. The results also showed that the disturbance created by a person in a flow field may be a very important factor to consider, when the person is turning the back to the flow field. It was found that the wake created behind a person was able to entrain contaminants from a distance exceeding the usual operation range. Guidelines for personal exposure reduction in a uniform velocity field are discussed.

METHODS

Full-scale Measurements

The measurements were performed in a wind channel (length x width x height = 2.44 m x 1.20 m x 2.46 m). A uniform velocity field was created by extracting air through two exhaust openings in the one end. The amount of exhausted air was adjusted to obtain a uniform velocity level in the wind channel ranging from 0.05 m/s to 0.45 m/s. The air temperature was kept constant at approximately 21°C.

A contaminant source was simulated by tracer gas injected through a porous foam rubber ball, ø 0.1 m. The tracer gas was a neutral density mixture of nitrous oxide and helium supplied at a very low velocity and at a temperature level corresponding to the temperature of the surrounding air.



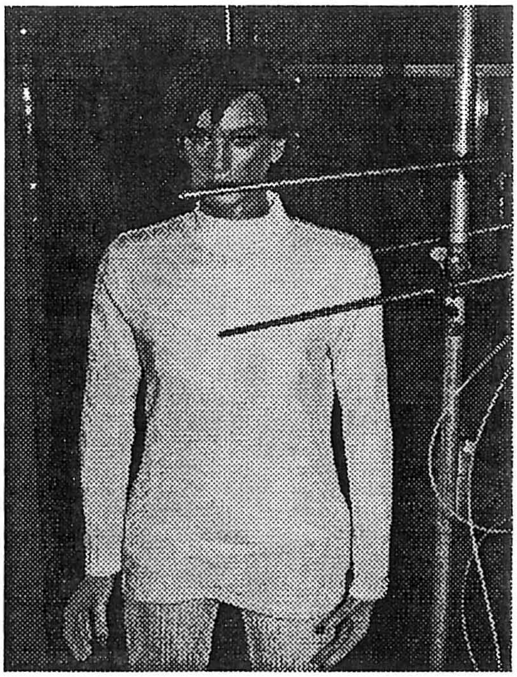


Figure 1. Breathing thermal manikin used to simulate a person at the full-scale measurements. In the background of the left photo the two exhaust openings in the wind channel are seen. In the foreground the spherical contaminant source is found.

To simulate a person the breathing thermal manikin shown in Figure 1 was used. The manikin is shaped as a 1.7 m high average sized woman. The tight-fitting clothes have an insulation value of 0.8 clo. The manikin consists of a fibre armed polyester shell, wound with nickel wire used sequentially both for the heating of the manikin and for measuring and controlling the skin temperature. The skin temperature and the heat output correspond to people in thermal comfort. Exposure measurements were performed with the thermal manikin by means of an artificial lung able to provide respiration through the mouth. Using a gas analyser, the concentration of inhaled tracer gas was found.

Computer Simulations

Computer simulations were performed by means of Computational Fluid Dynamics. Here the differential equations describing the flow field and the contaminant transport are translated into difference equations by dividing the solution domain into a large number of volumes. The differential equations are thus integrated over each volume giving a set of linear algebraic equations which can be solved using standard solution techniques (Patankar, 1980; Brohus, 1992).

In the computer simulations the person was modelled as a 1.7 m high cuboid with the same surface area as the clothed thermal manikin (1.6 m^2) and approximately the same convective heat output (25 W/m^2). The personal exposure was assumed to be equal to the concentration of contaminant in the close proximity of the cuboid in the breathing zone height (1.5 m above the floor).

RESULTS

A typical case was examined: A person facing a point contaminant source located at a horizontal distance of 0.25 m from the centerline of the person to the centerline of the source (see Figure 2 and Figure 3). The cross indicates the location of the contaminant source.

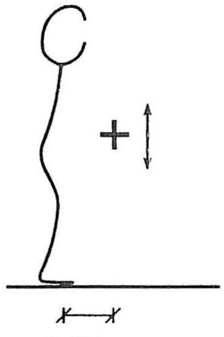


Figure 2. Location of the contaminant source relative to the person used in the full-scale measurements and the computer simulations. The cross shows the location of the source.

At this fixed horizontal location, measurements and simulations were done with the contaminant source vertically located at five different heights above the floor (0.50, 0.75, 1.00, 1.25 and 1.50 m).

This setup was repeated for three different directions of the uniform velocity field relative to the person corresponding to Case 1, Case 2 and Case 3 in Figure 3. For each case, four different velocity levels were examined (0.05, 0.15, 0.30 and 0.45 m/s). Whereas computer simulations were done for all three cases, only Case 1 included measurements.

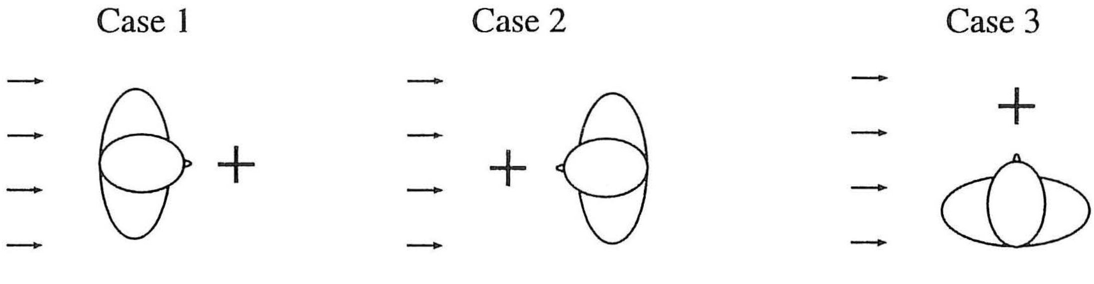


Figure 3. Location of the person and the contaminant source relative to the uniform flow field in the three cases examined in the present study.

In Figure 4 and Figure 5 results from the measurements and the simulations are presented. The figures show the personal exposure as a function of the velocity level and as a function of the vertical location of the contaminant source. Here, the personal exposure is defined as the concentration of inhaled contaminant made dimensionless by dividing with the concentration of contaminant in the air exhausted from the wind channel.

In that way the personal exposure level 1.0 corresponds to the situation where the air and the contaminant are fully mixed. Thus, if the exposure exceeds 1.0 the indoor air quality (IAQ) is worse than "fully mixing". Contrary, if the exposure is below 1.0 the IAQ is better than "fully mixing".

The curves are continuous interpolations based on the discrete results from the simulations and the measurements.

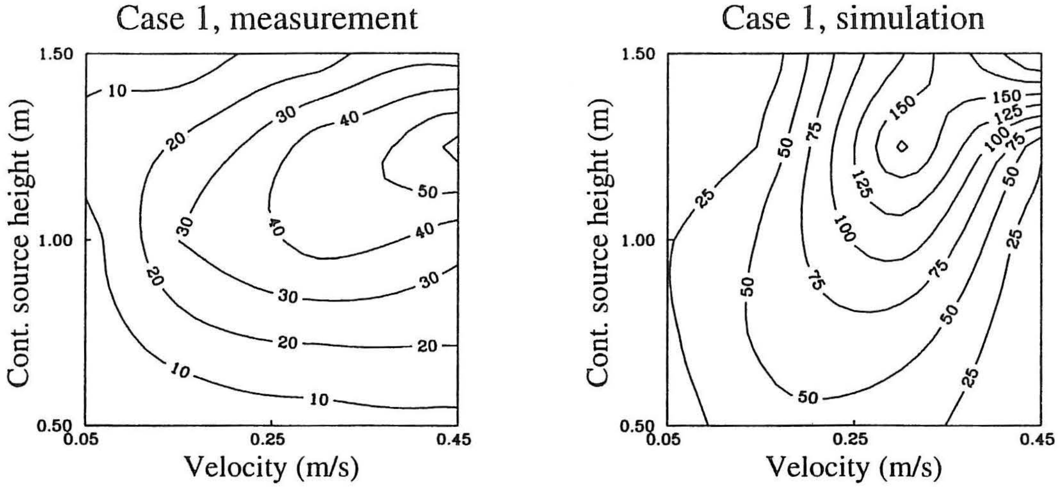


Figure 4. Personal exposure to the contaminant source in Case 1 as a function of the vertical location of the contaminant source and the uniform velocity level. Left: Full-scale measurements. Right: Computer simulations. The exposure is defined as the concentration of inhaled contaminant made dimensionless by dividing with the exhaust concentration of the wind channel.

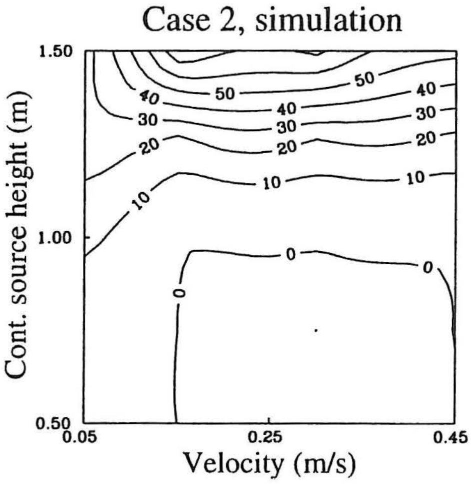


Figure 5. Personal exposure to the contaminant source in Case 2 as a function of the vertical location of the contaminant source and the uniform velocity level. Results from computer simulations. Exposure as defined in Figure 4.

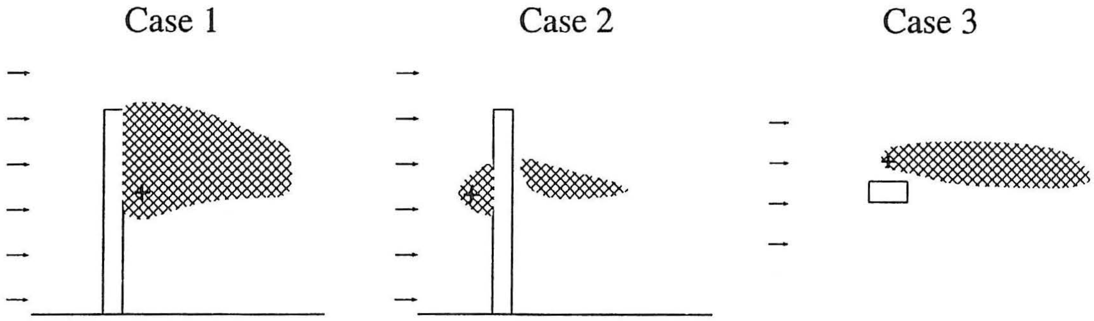


Figure 6. Example of the concentration distributions in the three cases for a fixed location of the source 1.0 m above the floor and the fixed velocity 0.3 m/s. The hatching represents areas where the local concentration exceeds the exhaust concentration more than 10 times. Left: Case 1 vertical symmetry plane. Centre: Case 2 vertical symmetry plane. Right: Case 3 horizontal plane 1.0 m above the floor.

To illustrate some fundamental phenomena that control the exposure, selected concentration distributions from the computer simulations are shown in Figure 6. In all cases the contaminant source is located 1.0 m above the floor and the uniform velocity is 0.3 m/s. A close-up of the flow field in the proximity of the simulated person is found in Figure 7 corresponding to Case 1 in Figure 6. Figure 7 is a top view of the velocity field 1.0 m above the floor.

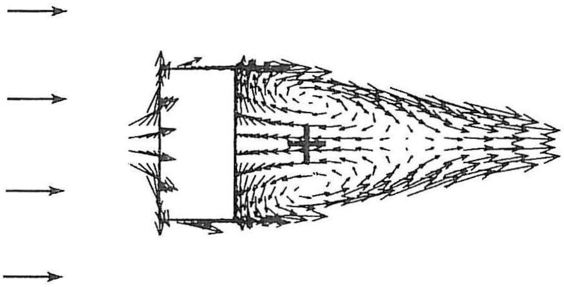


Figure 7. Close-up of computer simulated velocity field in front of the person in Case 1. Horizontal plane 1.0 m above the floor. Uniform velocity 0.3 m/s.

Computer simulations of Case 3 showed that no contaminant was transported to the breathing zone, even when the contaminant source was located at breathing zone height. Therefore, the personal exposure has been found to approach zero in Case 3.

DISCUSSION

Location of Person and Contaminant Source Relative to the Flow Field

Figure 4 shows the measurements and the simulations regarding Case 1. In this case vortices are generated in front of the person. These vortices are able to entrain contaminant from a certain distance and to transport it to the breathing zone. The vortex generation in front of the person corresponds well to earlier findings (Ljungqvist, 1979; Kim and Flynn, 1991) as well as smoke visualization in the laboratory. The transport of contaminant to the breathing zone is furthermore assisted by the ascending air currents in the thermal boundary layer that are generated along the person because of the excess surface temperature. This convective boundary layer may exert a significant influence at low velocities (Brohus and Nielsen, 1994).

The results demonstrate a considerable dependency on the velocity and on the location of the contaminant source. Both the measurements and the simulations show high levels of exposure, even when the contaminant source is located only 0.5 m above the floor. For the measurements, concentrations exceeding 50 times the exhaust concentration are found. For the simulations even larger values are found.

Comparing the measurements and the simulations reveals some deviation, typically a factor two or three. One reason for this may be the modelling of the full-scale thermal manikin as a simple heated cuboid. Another reason for this discrepancy may be found in the simulation of the very complex flow phenomena involved here.

If results from Case 2 are compared to Case 1 a very different pattern is found. Only for the contaminant source located above 1.0 m significant exposure levels are found. For a low location of the source, the flow removes the contaminant and prevents exposure.

Computer simulation of Case 3 did not show a significant exposure level. In this case the flow field removes the contaminant before it reaches the person.

Figure 6 shows the different concentration distributions for a fixed velocity level and a fixed contaminant source height. At the same time it illustrates some of the important flow phenomena that control the contaminant transport and, therefore, affect the personal exposure.

The horizontal distance between the person and the contaminant source has been kept constant. Investigations of a change in the horizontal distance between the person and the source from 0.25 m to 0.50 m show a reduction in exposure level, but the main conclusions are still the same. Therefore, the general conclusions stated above seem to be valid for sources in a distance of the person corresponding to a normal operation range.

Exposure Assessment

Usually, when personal exposure is assessed the room air is assumed to be fully mixed and the exposure is found by means of a simple mass balance. However, when the person is located in a room where a uniform velocity field prevails, the exposure may depend highly on the orientation of the person and the contaminant source relative to the flow field as mentioned above. The significant deviations from 1.0 in Figure 4 and Figure 5 indicate that exposure assessment may lead to erroneous results if the disturbance of the flow created by the person itself is ignored, and if the air and the contaminant are assumed to be fully mixed. Errors exceeding one order of magnitude could easily be obtained.

Exposure Reduction in a Uniform Velocity Field

When guidelines for exposure reduction are to be discussed, it is important to note that the present results, strictly speaking, are valid only for a person standing still and a specific contaminant type and location. In a real situation a person will move etc. Despite these differences some general conclusions may be drawn.

In both Case 1 and Case 2 a contaminant source located in the operation range of a person may cause high personal exposure. Especially in Case 1 it is important to be aware of the possible entrainment of contaminant in the wake generated in front of the person. The best way to control and to reduce exposure in a uniform velocity field is to employ Case 3. Here, the person who is facing the source turns the side to the flow field. In this case it is possible to remove the major part, if not all, of the contaminant before it comes into contact with the person.

ACKNOWLEDGEMENTS

This research was supported financially by the Danish Technical Research Council (STVF) as part of the research programme "Healthy Buildings", 1993-1997.

REFERENCES

Brohus,H., 1992, Air Flow in a Room Ventilated after the Mixing Principle with an Obstacle Placed in the Occupied Zone, *Proc. Fifth Nordic Seminar on Computational Mechanics*, pp. 146-150, Aalborg University, Aalborg, Denmark.

Brohus,H., Nielsen,P.V., 1994, Personal Exposure in Ventilated Rooms with Concentration Gradients, *Proc. Healthy Buildings '94, 3rd International Conference*, Vol.2, pp.559-564, Budapest, Hungary.

Kim,T., Flynn,M.R., 1991, Airflow Pattern Around a Worker in a Uniform Freestream, *Am. Ind. Hyg. Assoc. Journal, 52(7)*, pp. 287-296.

Ljungqvist,B., 1979, "Some Observations on the Interaction Between Air Movements and the Dispersion of Pollution", Swedish Council for Building Research, DOC D8:1979, Stockholm.

Patankar,S.V., 1980, " Numerical Heat Transfer and Fluid Flow" , Hemisphere Publishing Corporation.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 23: P. Kofoed, P. V. Nielsen: *Auftriebsströmungen verschiedener Wärmequellen - Einfluss der umgebenden Wände auf den geförderten Volumenstrom.* ISSN 0902-7513 R9151.

PAPER NO. 24: P. Heiselberg: *Concentration Distribution in a Ventilated Room under Isothermal Conditions.* ISSN 0902-7513 R9152.

PAPER NO. 25: P. V. Nielsen: *Air Distribution Systems - Room Air Movement and Ventilation Effectiveness.* ISSN 0902-7513 R9250.

PAPER NO. 26: P. V. Nielsen: *Description of Supply Openings in Numerical Models for Room Air Distribution* ISSN 0902-7513 R9251.

PAPER NO. 27: P. V. Nielsen: *Velocity Distribution in the Flow from a Wall-mounted Diffuser in Rooms with Displacement Ventilation.* ISSN 0902-7513 R9252.

PAPER NO. 28: T. V. Jacobsen & P. V. Nielsen: *Velocity and Temperature Distribution in Flow from an Inlet Device in Rooms with Displacement Ventilation.* ISSN 0902-7513 R9253.

PAPER NO. 29: P. Heiselberg: *Dispersion of Contaminants in Indoor Climate.* ISSN 0902-7513 R9254.

PAPER NO. 30: P. Heiselberg & N. C. Bergsøe: *Measurements of Contaminant Dispersion in Ventilated Rooms by a Passive Tracer Gas Technique.* ISSN 0902-7513 R9255.

PAPER NO. 31: K. S. Christensen: *Numerical Prediction of Airflow in a Room with Ceiling-Mounted Obstacles.* ISSN 0902-7513 R9256.

PAPER NO. 32: S. G. Fox & P. V. Nielsen: *Model Experiments in 1990 and On-Site Validation in 1992 of the Air Movement in the Danish Pavilion in Seville.* ISSN 0902-7513 R9335.

PAPER NO. 33: U. Madsen, N. O. Breum & P. V. Nielsen: *Local Exhaust Ventilation - a Numerical and Experimental Study of Capture Efficiency.* ISSN 0902-7513 R9336.

PAPER NO. 34: T. V. Jacobsen, P. V. Nielsen: *Numerical Modelling of Thermal Environment in a Displacement-Ventilated Room.* ISSN 0902-7513 R9337.

PAPER NO. 35: P. Heiselberg: *Draught Risk from Cold Vertical Surfaces.* ISSN 0902-7513 R9338.

PAPER NO. 36: P. V. Nielsen: *Model Experiments for the Determination of Airflow in Large Spaces.* ISSN 0902-7513 R9339.

PAPER NO. 37: K. Svidt: *Numerical Prediction of Buoyant Air Flow in Livestock Buildings.* ISSN 0902-7513 R9351.

PAPER NO. 38: K. Svidt: *Investigation of Inlet Boundary Conditions Numerical Prediction of Air Flow in Livestock Buildings.* ISSN 0902-7513 R9407.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 39: C. E. Hyldgaard: *Humans as a Source of Heat and Air Pollution.* ISSN 0902-7513 R9414.

PAPER NO. 40: H. Brohus, P. V. Nielsen: *Contaminant Distribution around Persons in Rooms Ventilated by Displacement Ventilation.* ISSN 0902-7513 R9415.

PAPER NO. 41: P. V. Nielsen: *Air Distribution in Rooms - Research and Design Methods.* ISSN 0902-7513 R9416.

PAPER NO. 42: H. Overby: *Measurement and Calculation of Vertical Temperature Gradients in Rooms with Convective Flows.* ISSN 0902-7513 R9417.

PAPER NO. 43: H. Brohus, P. V. Nielsen: *Personal Exposure in a Ventilated Room with Concentration Gradients.* ISSN 0902-7513 R9424.

PAPER NO. 44: P. Heiselberg: *Interaction between Flow Elements in Large Enclosures.* ISSN 0902-7513 R9427.

PAPER NO. 45: P. V. Nielsen: *Prospects for Computational Fluid Dynamics in Room Air Contaminant Control.* ISSN 0902-7513 R9446.

PAPER NO. 46: P. Heiselberg, H. Overby, & E. Bjørn: *The Effect of Obstacles on the Boundary Layer Flow at a Vertical Surface.* ISSN 0902-7513 R9454.

PAPER NO. 47: U. Madsen, G. Aubertin, N. O. Breum, J. R. Fontaine & P. V. Nielsen: *Tracer Gas Technique versus a Control Box Method for Estimating Direct Capture Efficiency of Exhaust Systems.* ISSN 0902-7513 R9457.

PAPER NO. 48: Peter V. Nielsen: *Vertical Temperature Distribution in a Room with Displacement Ventilation.* ISSN 0902-7513 R9509.

PAPER NO. 49: Kjeld Svidt & Per Heiselberg: *CFD Calculations of the Air Flow along a Cold Vertical Wall with an Obstacle.* ISSN 0902-7513 R9510.

PAPER NO. 50: Gunnar P. Jensen & Peter V. Nielsen: *Transfer of Emission Test Data from Small Scale to Full Scale.* ISSN 1395-7953 R9537.

PAPER NO. 51: Peter V. Nielsen: *Healthy Buildings and Air Distribution in Rooms.* ISSN 1395-7953 R9538.

PAPER NO. 52: Lars Davidson & Peter V. Nielsen: *Calculation of the Two-Dimensional Airflow in Facial Regions and Nasal Cavity using an Unstructured Finite Volume Solver.* ISSN 1395-7953 R9539.

PAPER NO. 53: Henrik Brohus & Peter V. Nielsen: *Personal Exposure to Contaminant Sources in a Uniform Velocity Field.* ISSN 1395-7953 R9540.

PAPER NO. 54: Erik Bjørn & Peter V. Nielsen: *Merging Thermal Plumes in the Indoor Environment.* ISSN 1395-7953 R9541.

Department of Building Technology and Structural Engineering
Aalborg University, Sohngaardsholmsvej 57. DK 9000 Aalborg
Telephone: +45 98 15 85 22 Telefax: +45 98 14 82 43